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Calculation of Tsunami Wave Run-Up and Velocity in Sidangoli Bay, West Halmahera

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Abstrak

Sistem tektonik geologisnya yang kompleks dan unik, Maluku Utara rentan terhadap bahaya tsunami. Penyebab tsunami kemungkinan besar adalah gempa megathrust. Meskipun korban jiwa relatif sedikit dan tsunami hanya terjadi secara lokal, dampaknya signifikan terhadap stabilitas wilayah. Salah satu wilayah yang tercatat dalam basis data tsunami purba Indonesia pada 28 Juni 1859, saat terjadi gempa bumi kuat di Laut Maluku dengan magnitudo 7, adalah Teluk Sidangoli, dengan ketinggian gelombang tsunami mencapai 10 meter. Oleh karena itu, perlu dilakukan perhitungan ketinggian gelombang dan kecepatan gelombang tsunami untuk mitigasi bencana tsunami. Metode perhitungan menggunakan persamaan matematika dengan program Python yang menggabungkan berbagai parameter. Pengolahan data menghasilkan model tsunami yang menunjukkan nilai ketinggian gelombang tsunami dan kecepatan gelombang tsunami di Teluk Sidangoli, Jailolo Selatan. Kecepatan propagasi gelombang tsunami mencapai 80 meter per detik, dan ketinggian gelombang tsunami mencapai 28 meter. Ketinggian dan kecepatan gelombang tsunami di Teluk Sidangoli sangat signifikan dan berpotensi menghancurkan segala sesuatu di jalurnya.

Abstract

Due to its complex and unique geological tectonic system, North Maluku is prone to tsunami hazards. The cause of the tsunami is likely to be a megathrust earthquake. Although there are few casualties and only localized tsunamis, they significantly affect the region's stability. One of the areas recorded by the Indonesian paleo tsunami database on 28 June 1859, when a strong earthquake occurred in the Maluku Sea with a magnitude of 7, was Sidangoli

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Bay, with a tsunami wave run-up of 10 meters. Therefore, it is necessary to calculate the run-up and velocity of tsunami waves to mitigate tsunami disasters. The calculation method uses mathematical equations with a Python program combining various parameters. The data processing resulted in tsunami modelling showing the run-up value and tsunami wave speed in Sidangoli Bay, South Jailolo. The tsunami wave propagation speed reached 80 meters/second, and the tsunami wave height reached 28 meters. The run-up and velocity of tsunami waves in Sidangoli Bay are significant and may destroy anything in their path.

Introduction

The seismotectonic situation in northern Maluku is influenced by several significant plates, minor plates, and island arcs, such as the Australian Plate, Eurasian Plate, Philippine Plate, Moluccas Sea, Sangihe Arc, and Halmahera Arc (Figure 1) (Cardwell & Isacks, 1978; Hamilton, 1979; Katili, 1978; Mccaffrey et al., 1980; Sandiford, 2010; Sukamto et al., 1981; Watkinson & Hall, 2017).

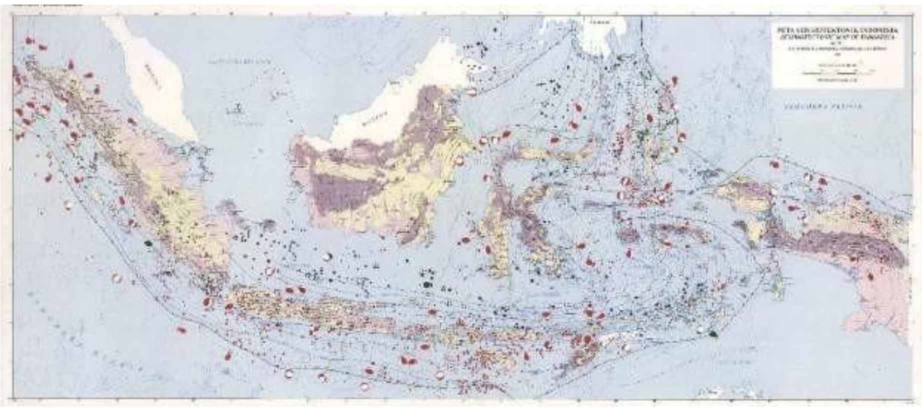

Figure 1
Seismotectonic Map of Indonesia

The collision of the converging Sangihe and Halmahera arcs created an active arc known as the Moluccas Sea (Cardwell et al., 1980; Hall, 1987; Hamilton, 1979; Hatherton & Dickinson, 1969; McCaffrey et al., 1980; Silver & Moore, 1978). These interactions cause tectonic activity centered in the Maluku Sea, which is very complex and causes various geological phenomena such as earthquakes, tsunamis, and volcanoes. The Moluccas Sea is one of the sources of earthquakes and tsunamis in North Maluku, including western Halmahera. The Moluccas Sea is considered an active tsunami area; 32 tsunami events have occurred, and earthquakes and volcanic eruptions caused 28 tsunamis caused four tsunamis.

Shallow earthquakes in this region mostly have thrusting fault focal mechanisms such as those in the Maluku Sea (Hamzah et al., 2000). Based on the paleotsunami database and local observation records in the bay of Sidangoli, West Halmahera, on 28 June 1859, there was an earthquake with a magnitude of 7 (Figure 2). The earthquake originated from the faulting of the Moluccas Sea Plate and caused a tsunami with a tsunami wave height of up to 10 meters (Harris & Major, 2017; Iida et al., 1967; Soloviev & Go, 1974). Tsunamis are usually initiated by a reverse fault focal mechanism of an earthquake, although in some cases, the 2018 tsunami in Palu was triggered by a strike-slip fault. However, this is unlikely (Sugito, 2008).

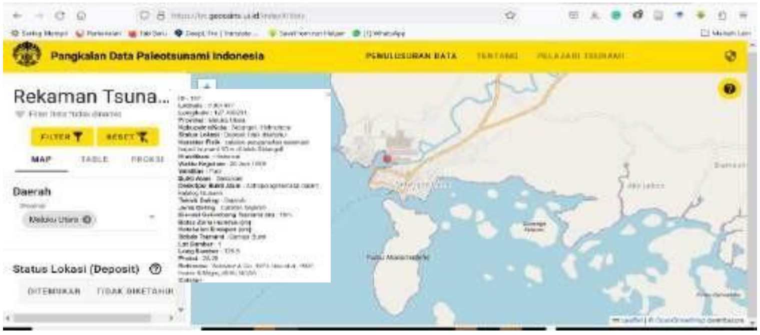

Figure 2
Information on Paleotsunami Data for the Sidangoli bay area, West Halmahera

Based on the information that has been described, this research aims to determine the potential tsunami hazard in Sidangoli Bay using geophysical methods. An overview to analyze and map the area's potential against tsunami hazards is the simulation of tsunami run-up and wave speed. Calculating simulated tsunami wave run-up and velocity uses Bayesian equations modeled with the help of the Python program. Tsunami information is modeled using Maluku Sea plate megathrust earthquake data. Tsunami wave run-up values are displayed in maps overlaid with topographic maps.

Methods

Topographic data of the study area and historical earthquake data, such as the location and magnitude of the hypocenter that triggered the tsunami, were used in modelling the tsunami wave run-up and velocity. This modelling uses the mathematical equation method with a Python program that combines various parameters. The bathymetry data used was BATNAS (National Bathymetry) water data and DEMNAS (National Digital Elevation Model) data (Figure 3).

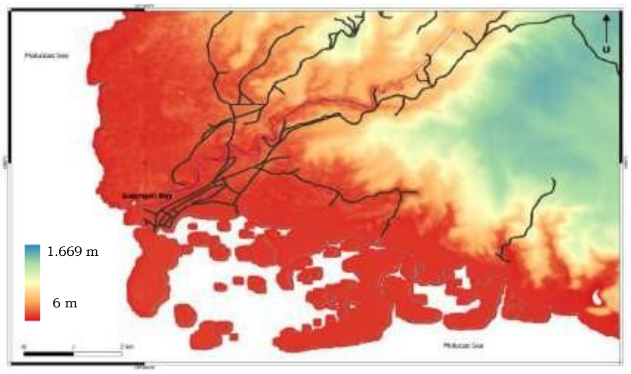

Figure 3
Topographical map of Sidangoli Bay and the surrounding area

The maximum vertical distance a tsunami wave crest can rise above the mean sea level is the tsunami run-up. This is an important indicator for understanding the possible hazards that a tsunami can pose as it measures the distance the waves can reach land or coastal settlements. On the other hand, Tsunami wave velocity is the velocity at which the wave travels through the water. Because the events that cause tsunamis (such as undersea earthquakes or volcanic eruptions) transfer large amounts of energy into them, tsunami waves travel significantly faster than regular ocean waves.

Most tsunamis are small waves in shallow seas that are never more than 5 kilometers deep. Shallow water is present when the water depth is less than half the wavelength. The data information obtained is used to calculate tsunami propagation using the equation (Komar, 1998; Okal, 1988; Pelinovsky, 1996; Satake, 1995; Trenhaile, 1997; Wiegel, 1964, 1970):

$$C = (gd)^{0.5} \qquad (1)$$

Where C is the wave speed (m/s), g is the acceleration of gravity (9.81 m/s2), and d is the water depth in meters. Velocity and depth are inversely proportional. Hence the depth is shallow, and the velocity will decrease at the coast. As a result, the tsunami height will increase (Wiji Raharjo, 2020) for the tsunami height of a single wave using the equation (Briggs et al., 1995; Camfield, 1994; Geist, 1977; Wiegel, 1964, 1970; H. . Yeh, 1991; H. Yeh et al., 1994):

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$$H_{max} = 2.83\,(\cot\beta)^{0.5} H_t^{1.25} \qquad (2)$$

Where H_{max} is the maximum tsunami run-up (meters), β is the shoreline slope angle (degrees), and H_t is the wave height at the beach or shore end (meters).

Result and Discussion

Calculation of tsunami wave run-up and velocity using the Python program. This program produces tsunami wave run-up and wave speed values in the form of maps using the Python base map. The hypocenter of the earthquake used was estimated to be in the subduction zone of the Maluku Sea with a magnitude of 7. Due to its potential as an earthquake source, the position of the hypocenter was chosen in modelling tsunami wave run-up and velocity. Tsunamis with a wave height of 10 meters historically occurred due to an earthquake in the Moluccas Sea in 1859. The Sangihe and Halmahera arc are island arcs that subduct beneath the Moluccas Sea. Thrust on either side of the Molucca Sea is directed towards the nearest arc as it subducts eastwards beneath Halmahera and westwards beneath the Sangihe Arc (Figure 4) (Waltham et al., 2008).

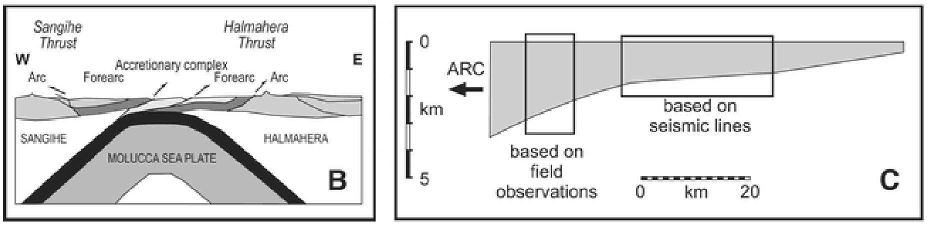
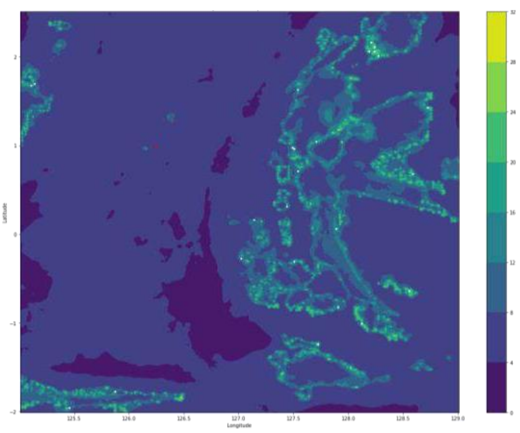
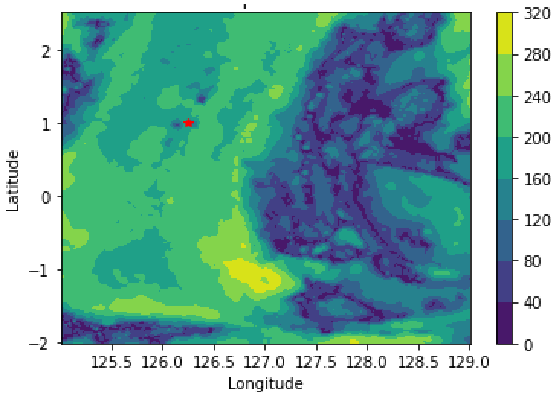


Figure 4
Illustration of the subduction zone between the Sangihe and Hakmahera arcs (Waltham et al., 2008)

Equations (1) and (2) were used to model the run-up and velocity of tsunami waves using topographic data around the study area. The modeled results can be seen in Figure 5 (a and b).



(a)



(b)

Figure 5
(a). Tsunami wave run-up model with scale in meters, (b). Tsunami Wave Velocity Model with scale in m/s

Based on Figure 5 (a and b), the tsunami wave run-up in Sidangoli Bay, influenced by the Maluku Sea subduction zone earthquake, reached 28 meters with tsunami wave velocities ranging from 0 to 80 m/s. The velocity decreases as the wave height increases. The run-up and height of tsunami waves in Sidangoli Bay are significant, and they may destroy anything in their path.

Sidangoli Bay is part of South Jailolo, West Halmahera, a tourist village and the center of sea transport and goods mobility. In the event of a tsunami, many facilities would be affected. Studies on tsunami run-up modelling and wave propagation speed are essential for disaster preparedness and mitigation. High wave speeds impact how quickly waves reach coastal areas after the event, while excessive run-up can cause extensive damage and inundate coastal communities. It is possible to plan infrastructure resilient to the tsunami threat with the help of an effective early warning system, which can be developed with a solid understanding of tsunami wave characteristics.

Conclusion

Tsunami hazard mapping using simple mathematical equations using topographical data from the study area and historical earthquake data in hypocenter location and magnitude resulted in the run-up and tsunami wave speed values. Based on the modeling, it can be concluded that a magnitude 7 SR earthquake can generate a tsunami in Sidangoli Bay with a speed of up to 80 meters/second and a tsunami wave height of up to 28 meters. The run-up and height of tsunami waves in Sidangoli Bay are significant, and they may destroy anything in their path.

As a tourist village, the center of sea transport routes and freight mobility has many supporting facilities. For disaster preparedness and mitigation, it is essential to identify locations that may be affected by tsunami waves, including the height and speed of tsunami waves. In addition, there is a need for a Tsunami Early Warning System in terms of systems and equipment as a form of information for the community.

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